

Prodrugs of DP IV-inhibitors

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A) According to the invention there are provided prodrug compounds of inhibitors of dipeptidyl peptidase (DP IV), which prodrug compounds have the general formula A-B-C, wherein

A is an amino acid,

B is a chemical bond between A and C or is an amino acid, and

C is a stable inhibitor of DP IV.

It has been found that administering inhibitors (effectors) of DP IV or DP IV-analogous enzyme activity in the blood of a mammal causes, because of the associated temporary reduction in enzyme activity, reduced breakdown of the endogenous (and also exogenously administered) insulino-tropic peptides Gastric Inhibitory Polypeptides 1-42 (GIP₁₋₄₂) and Glucagon-Like Peptide Amides-1 7-36 (GLP-17-36) (or also GLP-17-37 or analogues thereof) by DP IV and DP IV-like enzymes and, accordingly, the fall in concentration of those peptide hormones, or analogues thereof, is reduced or delayed. The greater stability of (endogenously present or exogenously introduced) incretins or analogues thereof, which results from the action of DP IV-effectors, increases their availability for insulinitropic stimulation of the incretin receptors of the Langerhans cells in the pancreas and alters, *inter alia*, the effectiveness of the body's own insulin, resulting in stimulation of carbohydrate metabolism in the treated organism. As a result, in the serum of the treated organism,

the blood sugar level drops below the glucose concentration that is characteristic of hyperglycaemia. Consequently, by means of DP IV-inhibitors it is possible to prevent or to mitigate metabolic anomalies such as excess weight, glucosuria, hyperlipidaemia and also possible serious metabolic acidoses and diabetes mellitus, which are a consequence of prolonged elevated glucose concentrations in the blood [see DE 196 16 486].

With the aid of DP IV-inhibitors, it is also possible, experimentally, to prevent the penetration of CD 26 (DP IV) positive cells by HIV [see WAKSELMAN, M., NGUYEN, C., MAZALEYRAT, J.-P., CALLEBAUT, C., KRUST, B., HOVANESSIAN, A.G., Inhibition of HIV-1 infection of CD 26+ but not CD 26- cells by a potent cyclopeptidic inhibitor of the DPP IV activity of CD 26. Abstract P 44 of the 24th European Peptide Symposium 1996].

It has also been found that DP IV can modulate the activity of neuroactive peptides, such as neuropeptide Y and CLIP [see MENTLEIN, R., DAHMS, P., GRANDT, D., KRUGER, R., Proteolytic processing of neuropeptide Y and peptide YY by dipeptidyl peptidase IV. Regul. Pept. 49, 133 (1993); WETZEL, W., WAGNER, T., VOGEL, D., DEMUTH, H.-U., BALSCHUN, D., Effects of the CLIP fragment ACTH 20-24 on the duration of REM sleep episodes. Neuropeptides, 31, 41 (1997)].

The problem of the present invention is to provide effectors of DP IV which have an increased action compared with known inhibitors and which have a temporally defined onset of action.

The problem is solved by providing prodrug compounds of inhibitors of dipeptidyl peptidase IV (DP IV), which prodrug compounds have the general formula A-B-C, wherein

A is an amino acid,

B is a chemical bond between A and C or is an amino acid,
and

C is a stable inhibitor of DP IV.

Surprisingly, inhibitors of that kind which are masked as prodrugs have significantly increased activity compared with non-masked inhibitors: When identical amounts of non-masked DP IV-inhibitors and of prodrug compounds according to the invention are used, an improvement in glucose tolerance of up to 75 % is obtained in Wistar rats; see also Table 4.

That improvement is all the more astonishing in view of the fact that it has been found that 100 % of non-masked inhibitors of DP IV are absorbed from the gastrointestinal tract of mammals and enter the vascular compartment of the body. It might, therefore, have been expected that prodrug compounds, which normally are intended only to prevent degradation of orally administered compounds in the gastrointestinal tract, would not lead to an increase in the activity of the inhibitors. Furthermore, it should be mentioned just in passing that there was no cause whatever for a person skilled in the art, on the basis of those facts, to look for modified inhibitors, even though prodrug compounds were known *per se*; see e.g. PCT/US 97/09421.

According to a preferred embodiment of the present invention, prodrug compounds are used in which B is proline, hydroxyproline, thiazolidinecarboxylic acid, dehydroproline, pipecolic acid, azetidinecarboxylic acid or aziridine-carboxylic acid, with proline and hydroxyproline being especially preferred. B preferably represents a peptide bond between A and C or is linked to A and C via peptide bonds.

The compounds according to the invention also have the advantage especially that the inhibitors of DP IV are released according to individual patient needs:

When a prodrug compound according to the invention interacts with a DP IV molecule, it is cleaved by the enzyme into the groups A-B and the inhibitor C. The inhibitor C will inhibit the DP IV molecule so that the latter cannot cleave any further prodrug compounds. When further DP IV molecules are present, prodrug compounds will be cleaved (if a sufficient amount of prodrug compounds has been administered) until the last DP IV molecule has been inhibited. The remaining prodrug compounds are not degraded and thus constitute an inhibitor reservoir until the concentration of DP IV molecules increases again or inhibitor molecules are displaced by DP IV or inhibitor molecules are eliminated, and the prodrug compounds are cleaved again, thus releasing inhibitors.

The invention therefore has the further advantage that each organism will release precisely the amount of inhibitor that is necessary to inhibit DP IV, which is present in different amounts in individual cases. If, for example, a patient has

a high concentration of DP IV, a large amount of inhibitor will be released; if there is only a slightly elevated concentration of DP IV, only a small amount of inhibitor will be released.

Furthermore, preference is given, according to the invention, to prodrug compounds wherein C is an aminoacylpyrrolidide, aminoacylthiazolidide or N-dipeptidyl, O-acyl hydroxylamine. Such inhibitors have shown themselves to be especially active DP IV-inhibitors. As examples of such inhibitors there may be mentioned, for example, Ile-Thia, Ile-Pyr, Val-Thia and Val-Pyr.

The inhibitors (component C) can, according to the invention, also be present in salt form, with organic salts such as acetates, succinates, tartrates or fumarates or inorganic acid radicals such as phosphates or sulphates being preferred. Fumarates are especially preferred.

Special preference is given to compounds wherein A-B is a dipeptide of formula Ile-Pro or Gly-Pro.

The present invention therefore relates to novel prodrug compounds of inhibitors of the serine peptidase dipeptidyl peptidase IV, which prodrug compounds can be used in the treatment of various disorders, especially metabolic disorders associated with diabetes mellitus.

A further advantage of the prodrug compounds according to the invention lies in the fact that it is possible for the onset of action and also the duration of action of the

DP IV-inhibitors to be temporally controlled by suitable selection of the groups A-B. In particular, the release of the groups A-B from the prodrug compounds according to the invention depends upon the nature of the amino acid radical of A: In respect of the definition of group A, the following sequence has been found, in particular, for the rate at which the radicals A-B are released from the prodrug compounds A-B-C by DP IV: Ile<Val<Phe<Pro<Ala<Gly. The rate constants of the corresponding DP IV-catalysed release reactions are between 1 s^{-1} and 100 s^{-1} . A means is thus available for releasing the DP IV-inhibitors in a precisely temporally defined manner: When the enzymes are to have an immediate onset of action, for example upon ingestion of glucose-rich nutrient, a compound A-B-C will be selected that has, for example, the amino acid Gly as group A; when the onset of action of the inhibitor is to be delayed, the amino acid Ile, for example, can be selected as group A. By means of the prodrug compounds according to the invention, therefore, it is possible for DP IV-inhibitors to be transported through the mucosa of the small intestine especially almost without a delay, for example almost simultaneously with ingested nutrients.

When B represents a bond, it is especially a peptide bond; when B represents an amino acid, it is linked to A and C preferably via peptide bonds.

On analysis of the dose-effect relationships of the DP IV-inhibitor isoleucyl thiazolidide as a modulator of the blood glucose concentration in the mammalian organism, a difference can be found between oral and parenteral

administration of the active substance to Wistar rats: On oral administration, saturation was observed in the uptake of the active substance (measured on the basis of inhibition of the serum enzyme), whereas on parenteral administration of the inhibitor complete inhibition of the enzyme was observed. That is demonstrated, by way of example, in Table 1:

Table 1: Residual activity of DP IV with respect to 0.4 mM of the substrate H-Gly-Pro-pNA at 30°C, pH 7.6 and an ionic strength of 0.125, after i.v. and p.o. administration and as a function of the isoleucyl thiazolidide (Ile-Thia) dose, determined 30 min after administration of the inhibitor.

Ile-Thia dose on parenteral administration	DP IV activity in %	Ile-Thia dose on oral administration	DP IV activity in %
0 mg	100	0 mg	100
0.02 mg	80	2.5 mg	52
0.2 mg	32	5.0 mg	40
2 mg	5	10 mg	28
20 mg	0	20 mg	29

In view of the fact that in the intestine there are also present enzymes, especially high concentrations of DP IV, that are capable of cleaving the cleavable groups of prodrugs and consequently of releasing the medicament and also - as already mentioned - it has been found that DP IV-inhibitors are absorbed quantitatively from the gastrointestinal tract, it was to be expected that the use of

prodrug compounds of DP IV-inhibitors would not bring about any improvement in that situation.

It was, therefore, extremely surprising to find that the prodrugs of DP IV-inhibitors according to the invention bring about clearly enhanced glucose tolerance in the glucose tolerance test compared with the corresponding non-masked DP IV-inhibitors. That behaviour was especially surprising because - as mentioned hereinbefore - it is possible for the prodrugs to be cleaved already in the intestine by enzymes present therein such as dipeptidyl peptidase and therefore, exactly like the non-masked inhibitors, ought no longer to be available for transport to the target site:

As soon as the prodrug compounds are cleaved by DP IV or other enzymes present in the intestine, the inhibitors according to the invention are released, which causes inhibition of DP IV in exactly the same manner as when non-masked inhibitors are used. Consequently, no further breakdown of the prodrug compounds by DP IV takes place; all prodrug compounds that are still undegraded or additionally introduced, as well as excess (that is to say, not bound to DP IV) non-masked inhibitors, can pass undegraded from the gastrointestinal tract into the vascular compartment of a body. There they can then be used as DP IV-inhibitors according to individual needs, as mentioned hereinbefore. However, after a certain time, the inhibitors bound to DP IV in the intestine are released again and enter the vascular compartment.

With the aid of the prodrug compounds according to the invention, it is therefore also possible to obtain a desired increase in action *in vivo*.

Moreover, it is possible to control the site of release and action of the DP IV-inhibitors by means of the nature of the radicals A-B:

Various other aminopeptidases such as, for example, pyroglutamyl aminopeptidase and prolyl aminopeptidase are present in the blood of mammals, in addition to dipeptidyl peptidase IV. By suitable selection of the radicals A-B, it is possible according to the invention to predetermine which aminopeptidase is to release the DP inhibitor and so to determine where the action of the inhibitor is to occur. The prodrug compounds according to the invention or corresponding pharmaceutical compositions can therefore be used in cell-, tissue- or organ-specific inhibition of DP IV. It is also possible to select the groups A-B so that only those enzymes that are present in the vascular compartment and that release the inhibitors at a sufficiently fast rate are targeted.

To summarise, it may be stated that, by means of the prodrug compounds of DP IV-inhibitors according to the invention, it is possible, in an entirely surprising manner:

1. to achieve increased action of the inhibitors;
2. for the inhibitors to be released according to patient needs;

3. for the inhibitors to be released from the prodrug compounds in a temporally controlled manner;
4. for the site at which the inhibitors are released from the prodrug compounds to be controlled; and
5. for a reservoir of DP IV-inhibitors to be provided.

According to the invention, pharmaceutical compositions, especially for oral administration, are also provided, which are characterised in that they comprise at least one prodrug compound according to the invention optionally in combination with customary carriers or excipients.

The prodrug compounds or pharmaceutical compositions comprising them in accordance with the invention can be used in the treatment or prophylaxis of disorders in mammals that can be treated by modulating the DP IV activity of a mammal, such as, for example, metabolic disorders in humans.

In particular, they can be used in the treatment of impaired glucose tolerance, glucosuria, hyperlipidaemia, metabolic acidoses, diabetes mellitus, diabetic neuropathy and nephropathy and of sequelae of diabetes mellitus in mammals.

Examples

1. Synthesis of prodrug compounds according to the invention

1.1. Synthesis of H-Pro-Ile-Thia/HCl

6.5mM Boc-Pro-Ile-OH (one equivalent = 1 eq.) is suspended, together with N-hydroxybenzotriazole (1 eq.) and thiazolidine (1 eq.), in 30 ml of dichloromethane (DCM). The equivalent amount of 1M dicyclohexylcarbodiimide solution is added dropwise, at -10°C , with stirring. Stirring is carried out at -10°C and overnight at room temperature. For the purpose of working-up, the solution is thoroughly filtered off from the dicyclohexylurea that is precipitated out, DCM is drawn off in vacuo and the residue obtained is taken up in ethyl acetate. The ethyl acetate solution is washed at least three times with saturated bicarbonate solution, once with saturated NaCl solution, three times with dilute KHSO_4 solution and again with NaCl solution. The ethyl acetate phase is dried over Na_2SO_4 and concentrated using a rotary evaporator, and the remaining crude product is recrystallised using ethyl acetate/pentane. Boc-Pro-Ile-Thia crystallises after 1-2 days at 4°C (yield 80 %). 1.1N HCl/glacial acetic acid solution is added to Boc-Pro-Ile-Thia (3 ml per mmol of peptide). Stirring is carried out for two hours at RT, absolute ether is added and excess removal solution is evaporated off using a rotary evaporator. The hydrochloride crystallises quantitatively under absolute ether overnight at 4°C . The crystals are quickly separated off by suction filtration, washed several times with

absolute ether, and the product is stored in a desiccator over KOH or phosphorus pentoxide.

1.2. Synthesis of H-Gly-Pro-Ile-Thia/HCl

Boc-Gly-OH (1 eq.) is dissolved in 20 ml of tetrahydrofuran (THF), cooled to -10°C and, with stirring, N-methylmorpholine (1 eq.) and chloroformic acid isobutyl ester (1 eq.) are added in succession. Activation is carried out for about 20 min. In parallel, Pro-Ile-Thia.HCl (1 eq.) is suspended in 10 ml of THF, equilibrated to -10°C , and N-methylmorpholine (1 eq.) is added for the purpose of neutralisation. After completion of the activation time, both solutions are mixed together and, after one to two hours, heated to room temperature and stirred overnight. A small amount of water is then added to the reaction mixture and the THF is distilled off *in vacuo*. The remaining residue is taken up in ethyl acetate and washed at least three times with saturated sodium bicarbonate solution, once with saturated NaCl solution, three times with dilute KHSO_4 and again with saturated NaCl solution. The ethyl acetate phase is dried over Na_2SO_4 , concentrated using a rotary evaporator and the product Boc-Gly-Pro-Ile-Thiazolidide is recrystallised using ethyl acetate/pentane (yield 85 %). The removal of Boc is carried out analogously to the synthesis of H-Pro-Ile-Thia/HCl (yield > 95 %).

Table 2: Analytical data for prodrugs of inhibitors of dipeptidyl peptidase IV

Substance	MW, calculated* [g/mol]	MW, found M + H ⁺	CE purity, retention time (Rt)	HPLC purity Rt	Melting point °C
pGlu-Ile-Thia*HCl	349.84	314.8	4.2 min	10.4 min	30-40
Pro-Ile-Thia*HCl	335.90	300.8	4.5 min	10.05 min	45-69
Gly-Pro-Ile-Thia*HCl	392.94	357.8	4.6 min	8.8 min	111-121
Ile-Pro-Ile-Thia*HCl	449.05	413.6	5.6 min	10.0 min	98-107
Pro-Pro-Ile-Thia*HCl	433.01	397.6	5.3 min	11.35 min	101-118

Conditions for the analysis:

HPLC Column: LiChrospher 250-4, 100 RP-18.5 µm, temperature 25°C
 Eluant: 30 % ACN, 0.1 % TFA, isocratic, flow rate 0.5 ml/min
 Detection wavelength: 210 nm

CE Capillary: 30 cm x 50 µm fused silica, temperature 25°C
 Detection wavelength: 200 nm
 Injection: 5 sec, 50 mbar
 Separation: 0.1M Na phosphate buffer, pH 2.5; duration 7 min at 12 kV

2. Affinity and transport of various peptides, DP IV-inhibitors and prodrugs to the peptide transporter PepT1

The affinity of various peptides, DP IV-inhibitors and prodrugs of inhibitors of DP IV to the peptide transporter PepT1 were analysed by displacement of the radioactively labelled substrate D-Phe-Ala (AMASHEH, S., WENZEL, U., WEBER, W.M., CLAUSS, W., DANIEL, H., Electrophysiological analysis of the function of the mammalian renal peptide transporter expressed in *Xenopus laevis* oocytes. J. Physiol. 504, 169-174 (1997)]. It is shown that, for example, the

tetrapeptide derivative Ile-Pro-Ile-Thia becomes bound to the transporter protein PepT1 in a comparable manner to, or better than, selected amino acid derivatives and, in comparison with selected amino acid and peptide analogues, is transported in a similar or better manner (Table 3).

Table 3: Transport properties of various amino acid and peptide derivatives on the human peptide transporter PepT1

Amino acid or peptide derivative	Electrophys. transport analysis (hPEPT1 expr. in oocytes), flux % based on the Gly-Gln control (100 %)	Binding constant, mM, to PepT1, relative to D-Phe-Ala
Lys-Phe	95	0.08
Lys-Phe-Pro	10	0.19
Asn-Pyr	30	3.01
Asn-Thia	83	0.50
His-Pyr	7	5.34
His-Thia	12	0.57
Ile-Pyr	14	2.66
Ile-Thia	25	0.98
Ile-Pro-Ile-Thia	44	0.61

Release of the active DP IV-inhibitor Ile-Thia from prodrugs according to the invention in human whole blood

According to an embodiment of prodrugs of DP IV-inhibitors according to the invention, retarded release of DP IV-inhibitors in the target compartment, for example, in the blood circulation, is also possible.

Figure 1 shows, by way of example, the inhibition of human blood-DP IV resulting from release of the inhibitor

isoleucyl thiazolidide from prodrug compounds according to the invention, the inhibition following different courses as a function of time. Release of the masked DP IV-inhibitor in the blood can be carried out, in the case of the examples selected, by DP IV itself (Pro-Pro-Ile-Thia = PPIThia, Gly-Pro-Ile-Thia = GPIThia) or by aminopeptidases (pGlu-Ile-Thia = pEIThia, Pro-Ile-Thia = PIThia) (Figure 1). When the same concentration of prodrug compound is used, there is a difference in the efficiency with which the DP IV-inhibitor isoleucyl thiazolidide is released from the prodrug compounds in the blood, a more marked delay in the release of active substance being shown in the case of Pro-Pro-Ile-Thia (PPI Thia) and pGlu-Ile-Thia (pEI Thia) compared with Pro-Ile-Thia (PI Thia) and Gly-Pro-Ile-Thia (GPI thia).

3. Enhancement of DP IV-inhibitor-imparted glucose tolerance resulting from the use of prodrugs

As a result of converting the active substance isoleucyl thiazolidide into prodrugs according to the invention, a markedly improved profile of action is observed in the Wistar rat following oral administration (Figure 2). The desired reduction in the level of blood glucose caused by DP IV-inhibitors in the time period examined is enhanced by about 30 % by using the prodrug compounds according to the invention as opposed to the non-masked active substance Ile-Thia (Table 4):

Active substance/prodrug	% glucose level
control	100
Ile-Thia	74.4
Gly-Pro-Ile-Thia	57.1
Pro-Ile-Thia	56.1

Active substance/prodrug	% glucose level
control	100
Ile-Thia	74.4
Gly-Pro-Ile-Thia	57.1
Pro-Ile-Thia	56.1